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$K\alpha$ LINE EMISSION DURING SOLAR X-RAY BURSTS

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Abstract

Calculations of Kα line emission from S, Ar, Ca and Fe are presented. On the basis of Kane and Anderson's data for hard x-ray bursts, the flux during most impulsive, non-thermal events is likely to be weak, though for a few strong bursts, a flux of ~100 photons cm^{-2} s^{-1} may be expected. The amount of S Kα emission particularly is sensitively dependent on the value of the lower energy bound of the non-thermal electron distribution, offering a possible means of determining this. Thermal Kα emission is only significant for Fe ions. The calculated thermal Kα radiation is much less than that observed during an intense soft x-ray burst. It seems that a detailed temperature structure for the emission source is required in order to explain the discrepancy.

1. Introduction

The existence of highly energetic non-thermal electrons has been deduced by several investigators from the occurrence of impulsive bursts of hard x-rays. Parks and Winckler (1969), Kane (1969) and Frost (1969) have noted that such bursts, with typical durations of 10-60 seconds, may occur singly or multiply near the outset of the flare event. Each burst usually has a power-law photon spectrum of the form F (photons cm^{-2} s^{-1} keV^{-1}) $\propto (h\nu)^{-\Phi}$ where $\Phi \simeq 2$ or 3 for energy ranges of the order of 10-80 keV. The intensity falls off much more rapidly beyond the upper energy bound. More gradual bursts with spectra which are much steeper and are probably thermal in origin may accompany these impulsive events. Frost and Dennis (1970) have also observed a long-enduring burst with a very hard photon spectrum, quite distinct from thermal emission. Such a burst may represent the acceleration of electrons to relativistic energies as considered by de Jager (1969).

Electron distributions which would give rise to the observed x-ray emission above 10 keV during non-thermal events have been described by Frost (1969), who discusses a narrow Gaussian profile in energy, and by Holt and Cline (1968), Holt and Ramaty (1969), Takakura (1969) and Kane and Anderson (1970) who find that a power law in electron energy satisfactorily reproduces the x-ray spectrum. Frost (1969) has found that the x-ray spectrum of a non-thermal impulsive burst is a power-law with photon energy up to about 100 keV beyond which there is a marked steepening. It is known that fewer electrons escape into interplanetary space at energies greater than approximately this value (Lin and Hudson 1970). Some recent work by Brown (1972) suggests that the electron energy distribution may be much steeper than that derived in, e.g., Kane and Anderson's (1970) analysis since account should be taken of a variable ambient particle density along the magnetic flux tube containing the energetic electrons. This, unlike a uniform-density thin-target model, can explain a softening of the x-ray spectrum with time after event maximum as is observed for impulsive events.

Streams of energetic electrons such as those present during impulsive bursts may cause ionization of target atoms through the removal of inner-shell electrons. A rearrangement process may take place in the remaining orbiting electrons with excess energy carried away by an Auger electron, but there is an increasing probability of photon emission occurring for increasing atomic number, Z. Removal of a K-shell electron, for example, and the subsequent filling of a vacancy with an L-shell electron, gives rise to so-called Kα line emission. Acton (1965) has presented a simple calculation of the likely flux of iron Kα radiation during a non-thermal solar event, predicting that the emission (at 1.85 - 1.94Å) should be observable above the Bremsstrahlung continuum produced by the same non-thermal electrons. Alternatively, electrons in the high-energy tail of a Maxwellian distribution may give rise to K-shell ionization. However, at temperatures which are high enough for a substantial number of energetic electrons to be present, collisional ionization of the outer electrons of target atoms may deplete almost entirely those in neutral or weakly ionized stages. Hence Kα transitions in only certain ionization stages may be visible. In the following sections, we examine the likelihood of $K\alpha$ emission during both non-thermal and thermal solar flare phenomena from four elements abundant in the solar corona.

2. K-shell ionization and $K\alpha$ transitions

The removal of a K-shell electron of an atom by electron impact may be followed by either a rearrangement process in the remaining atomic electrons with the ejection of an Auger electron or the filling of the vacancy by an L-shell electron with $K\alpha$ photon emission. The probability of the radiative transition occurring is expressed by the K-fluorescence yield, $\omega_{K,Z}$, which increases with atomic number, Z. Radiative transitions are permitted for any of the six 2p electrons (assuming this subshell was complete before impact), but forbidden for the two 2s electrons. The transition of a 2p electron to the 1s shell leaves a 2p 'hole' in either a $^2P_{1/2}$ or $^2P_{3/2}$ level (L_2 and L_3 in x-ray terminology), so that there are two closely spaced $K\alpha$ lines: $K\alpha_1$ (K - L_3 transition) and $K\alpha_2$ (K - L_2). Tabulations of $\omega_{K,Z}$ (Fink et al. 1966) give the combined K-fluorescence yields for the two lines since their energy separation is small. Wavelengths of such $K\alpha$ transitions for a large range of elements and ionization stages have been calculated by House (1969). Veigele (1970) has considered the possibility of $K\alpha$ satellites near the $K\alpha_1$ and $K\alpha_2$ lines in which the initial configuration has both a 1s and 2s electron removed. Such transitions may occur in the sun but are likely to be much fainter than $K\alpha_1$ and $K\alpha_2$.

The flux of $K\alpha$ emission from atoms of atomic number Z in a solar plasma, resulting from electron impact, is given by

$$F_Z = \frac{V\omega_{K,Z}\, f\, n_Z}{4\pi r^2} \int_{E_1}^{E_2} v \frac{dn_e}{dE} Q_Z(E)\, dE \text{ photons cm}^{-2}\text{ s}^{-1} \tag{1}$$

where V is the source volume, n_Z the number density of target atoms and f the proportion of them in the boron-like ionization stage (ground state configuration $1s^2\ 2s^2\ 2p$) or lower. (We shall see in section 4 that K-shell ionization of the beryllium-like and higher stages in elements we consider does not produce Kα transitions in the solar atmosphere.) r is the earth-sun distance, while the energy distribution of impinging electrons is dn_e/dE ($E_1 < E < E_2$), their velocity v, and Q_Z the cross section for K-shell ionization. Values for Q_Z can be derived from a theory of Arthurs and Moiseiwitsch (1958) which uses a relativistic treatment of the Born approximation. This has given an accurate representation of laboratory data (Motz and Placious 1964; Kolbenstvedt 1967) so it should be adequate for our purposes. Their formulation uses an effective nuclear charge $Z_e = Z - 0.3$. The screening constant of 0.3 applies to the 1s electron remaining after K-shell ionization, electrons outside the 1s shell having negligible effect (Slater 1930). Thus the calculations are valid for all ionization stages up to the helium-like ion as well as for the neutral atom.

We have determined F_Z for both non-thermal and thermal distributions of energetic electrons likely to exist during solar flares. Elements having reasonable abundances in the solar corona ($n_Z/n_H > 10^{-6}$) and with K-ionization potentials larger than 2 keV were selected. Only sulfur, argon, calcium and iron satisfy both criteria. Necessary data for these elements are given in Table I.

Table I.

K-Ionization Data for Four Elements

Element	Z	$\omega_{K,Z}$	log (n_Z/n_H)	K-Shell I.P.(keV)*	$K\alpha$ Wavelengths** (Å)
Sulfur	16	.09	$-4.4^{\dagger}$	2.47	5.37
Argon	18	.13	$-6.5^{\ddagger}$	3.21	4.19
Calcium	20	.17	$-5.6^{\ddagger}$	4.04	3.36
Iron	26	.31	$-4.0^{\ddagger}$	7.12	1.94

*International Tables for X-Ray Crystallography, vol. III (1962)
† Pottasch (1967)
‡ de Boer et al. (1972)
**House (1969). Wavelengths are for first ionization stage.

3. Kα emission during impulsive hard x-ray events

To calculate Kα emission during non-thermal impulsive events seen at high energies, we follow the analysis of Kane and Anderson (1970) and Lin and Hudson (1971), using the notation of the latter work. These authors show that the power-law photon spectrum during an impulsive burst,

$$\frac{dJ(h\nu)}{d(h\nu)} = B\ (h\nu)^{-\Phi} \text{ photons cm}^{-2}\ \text{s}^{-1}\ \text{keV}^{-1}\ (10 \lesssim E \lesssim 80 \text{ keV}) \qquad (2)$$

can be closely reproduced by a thin-target Bremsstrahlung spectrum emitted by electrons with a distribution

$$\frac{dn_e}{dE} = A\,E^{-\delta} \text{ electrons cm}^{-3}\text{ keV}^{-1} \quad (10 \lesssim E \lesssim 80 \text{ keV}) \tag{3}$$

as they collide with the atoms of a coronal plasma ($T \simeq 2 - 4 \times 10^6$ K). The exponents δ and Φ are related through figure 4 of Lin and Hudson's paper, for which the approximation

$$\delta = \Phi - 1.25 \tag{4}$$

holds reasonably well. The coefficients A and B are related by

$$B = 4.09 \times 10^{-43}\, n_i\, VA\, K(\delta) \tag{5}$$

where n_i is the ion density of the coronal plasma and $K(\delta)$ is also given by Lin and Hudson as a function of δ.* We are assuming that the non-thermal electrons giving rise to Bremsstrahlung with a photon spectrum described by (2) also cause K-shell ionization of target atoms in the coronal plasma, in particular those of elements listed in Table I. We hence replace dn_e/dE in (1) by (3) and (with $n_i \simeq n_H$) use (5) so that F_Z is given by

$$F_Z = \frac{B\,\omega_{K,Z}}{4.09 \times 10^{-43}\, K(\Phi - 1.25) \times 4\pi r^2}\; \frac{fn_Z}{n_H} \int_{E_1}^{E_2} vE^{-\Phi+1.25}\, Q_Z(E)\,dE$$

$$\text{photons cm}^{-2}\text{ s}^{-1}. \tag{6}$$

*An error of a factor 1.602 in Lin and Hudson's analysis (Lin, private communication) is corrected by the constant of equation (5). Values of $K(\delta)$ from their Figure 5 (not their equation (6)) should be inserted in our equation (5).

In Figures 1-4, we present the results of calculations of F_Z/B for various values of Φ, the integral having been evaluated numerically by Simpson's approximation. E_2 is taken to be 80 keV and E_1 a free parameter in the range 0-35 keV; we have in mind Kahler and Kreplin's comments (Kahler and Kreplin 1971) on the possibility of E_1 being lower than 10 or 20 keV, values given in Kane and Anderson's analysis. Kahler and Kreplin noted two instances in which an impulsive high-energy burst seen by Kane and Anderson is reproduced at energies down to 3 keV as observed by their proportional-counter spectrometer on OGO-5.

Values of f, the quantity introduced in (1), are given in Table II for the four elements considered here as a function of the temperature, T_o of the target atoms. At coronal temperatures ($\sim 2 \times 10^6$K), these elements are ionized generally only as far as the B-like stage ($f \simeq 1$). However, we recall observations of a slow rise in soft x-ray intensity several minutes before the main enhancement (Teske and Thomas 1970) with accompanying temperature rise. Kahler and Kreplin (1970) have mentioned that there may be a slow rise to $T \simeq 10^7$ K when a thermal instability occurs. At such a temperature, f would be much less than unity (particularly for sulfur and argon), giving a corresponding reduction in Kα flux.

Table II

Proportion of Target Atoms Ionized to B-like Stage or Lower (f) as a Function of Target Plasma Temperature (T_o)

log T_o	f			
	Sulfur*	Argon†	Calcium†	Iron‡
6.3	0.84	1.00	1.00	1.00
6.4	0.40	0.96	1.00	1.00
6.5	0.072	0.73	0.99	1.00
6.6	0.0086	0.30	0.89	1.00
6.7	0.0013	0.057	0.55	1.00
6.8	0.00025	0.0089	0.16	1.00
6.9	0.000062	0.0016	0.030	1.00
7.0	0.000015	0.00039	0.0058	0.95

*Jordan (1969)

†Landini and Fossi (1972)

‡Jordan (1970)

Kane and Anderson have tabulated B and Φ for thirteen hard x-ray bursts in 1968. Using (6), we can thus calculate F_Z during these events for the elements of Table I. The results are summarized in Table III for E_1 = 10 keV and for values of f corresponding to a target plasma temperature $T_o = 2 \times 10^6$ K. For comparison, we show values for E_1 = 3 keV for the April 16 and May 10 events. These are the two bursts for which Kahler and Kreplin (1971) observe a low-energy counterpart.

We see that certain events may have given rise to an observable amount of Kα radiation from at least iron and sulfur, though the emission from other elements is generally weak. In particular, the events of April 16 and May 10 would have given rise to only small Kα fluxes even though the electron power-law energy distribution may have extended down to E_1 = 3 keV.

Two further comments of possible interest can be made. First, Figure 1 shows that the amount of sulfur Kα emission is particularly sensitive to E_1, for even rather small values of Φ. This may offer a means of deducing the low-energy bound of the distribution of energetic electrons for sufficiently large impulsive bursts. Secondly, Tomblin (1972) has calculated that Compton back-scattering from the photosphere may contribute emission at high energies for flares on the solar disk, tending to harden a flare x-ray spectrum. He finds that a flare near the disk center with an observed photon spectrum power-law index of Φ = 2.8 would have had Φ = 3.2 with the Compton back-scattering component removed. A consequence is that the Kα emission as calculated in Table III would be decreased for all events occurring near the sun's disk center. However, the fluxes for some bursts (notably April 30, May 10 and June 26, 1968)

Table III

$K\alpha$ Emission During Kane and Anderson's Events

Event Date (1968)	F_Z (photons cm^{-2} s^{-1})			
	S	Ar	Ca	Fe
April 13	3	0.02	0.2	5
16 (E_1 = 3 keV)	9	0.1	0.9	21
(E_1 = 10 keV)	8	0.1	0.6	20
29	56	0.6	3.8	97
30	43	0.4	2.9	74
May 3	40	0.4	2.7	67
10 (E_1 = 3 keV)	78	0.5	2.7	38
(E_1 = 10 keV)	18	0.2	1.2	32
22	149	1.4	10.3	245
24	18	0.2	1.4	43
25	10	0.1	0.7	21
28	90	0.9	6.3	156
June 15	70	0.6	4.6	108
20	52	0.5	3.3	79
26	111	1.1	7.6	221

would remain unaffected since these occurred near the limb.

Brown (1972) has suggested that possible variations in the ambient density (n_Z in equation (6)) of the hard x-ray source region may result in a much steeper electron spectrum. It is found that δ may be increased by 2 or more powers if n_Z is taken to have a dependence on electron energy, E, of the form $n_Z \propto E^{\alpha}$. This has no effect on the present calculations. In equation (4), Φ - 1.25 is either δ if uniform n_Z is assumed (i.e., $\alpha = 0$) or $\delta - \alpha$ if density effects are included.

4. Kα emission during thermal events

We now calculate Kα radiation emitted by high temperature flare plasmas such as are inferred from soft x-ray bursts. Soft x-ray events follow the hard impulsive bursts referred to earlier, last for some 3-70 minutes, and exhibit temperatures as high as 2 or 3 x 10^7 K (Neupert et al. 1969, Kahler et al. 1970, Milkey et al. 1971). At T = 3 x 10^7 K, 14% of electrons have energies in excess of the K-shell ionization potential of neutral iron which is 7.12 keV. On the other hand, collisional ionization at such temperatures will strip most of the atoms of the four elements we consider to the He-like or H-like ionization stages for which Kα transitions are no longer possible. In fact, appreciable Kα emission only arises from a few high ions in iron, so we shall evaluate the Kα flux from some specific stages as a function of temperature.

In equation (1), we replace dn_e/dE by the Maxwellian function giving

$$F_{Z,i} = \frac{V\,\omega_{K,Z}\,n_{Z,i-1}}{4\pi r^2} \int_0^\infty \frac{8\pi\, m\, n_e}{(2\pi\, m\, k\, T)^{3/2}}\, Ee^{-E/kT}\, Q_Z\,(E)\, dE$$

$$\text{photons cm}^{-2}\,\text{s}^{-1} \qquad (7)$$

for the flux of Kα line emission from the i th ionization stage, or, numerically (with $n_i \simeq n_H$),

$$F_{Z,i} = 2.98 \times 10^{-8}\, n_i\, n_e\, V\, \omega_{K,Z}\, \frac{n_{Z,i-1}}{n_Z}\, \frac{n_Z}{n_H}\, X$$

$$X \int_0^\infty \frac{E\, e^{-E/kT}}{T^{3/2}}\, Q_Z\,(E)\, dE \text{ photons cm}^{-2}\,\text{s}^{-1} \qquad (8)$$

where m is the electron mass, k Boltzmann's constant, and T the electron temperature. We have replaced n_Z, the number density of atoms of atomic number Z, by $n_{Z,i-1}$, the number density of ions in the (i - 1) th stage about to be K-shell ionized to the i th stage. Plots of $F_{Z,i}$ against T are shown in Figure 5 for emission from the ions Fe XVIII - XXIV. An emission measure ($n_i\, n_e$ V) of 10^{48} cm^{-3} is assumed. The integration over electron energy, E, has been carried out using Simpson's rule with an effective limit of 55 keV.

Kα emission from Li-like and He-like iron (Fe XXIV and XXV) is possible but in each case K-shell ionization of ions in excited configurations must occur. For example, the 1s2p - $1s^2$ transition in Fe XXV could arise from the K-shell ionization of Fe XXIV with a $1s^2$ 2p configuration. However, Gabriel (1972) has calculated that most Fe XXIV ions are in the ground state configuration $1s^2$ 2s for densities less than 5×10^{18} cm^{-3}, several orders of magnitude above solar flare densities.

This applies to the other elements we considered in Section 2, viz. sulfur, argon and calcium. For these, densities of at least 5×10^{17} cm^{-3} at temperatures of a few 10^7 K are required for a Boltzmann distribution between $1s^2 2s$ and $1s^2 2p$ to be set up. A similar argument applies to the $1s2s2p - 1s^2 2s$ transition in Fe XXIV, the upper level of which may be produced by the K-shell ionization of Fe XXIII ions in a $1s^2 2s2p$ configuration. Kα emission from Fe XXIV is plotted in Figure 5 on the assumption that all target Fe XXIII ions had a $1s^2 2s2p$ configuration. The curve should be modified by a factor β, the proportion of Fe XXIII ions actually in this configuration. For the small densities of solar x-ray flare plasma, β is near zero. A Boltzmann distribution between the $1s^2 2s^2$ and $1s^2 2s2p$ configuration (when $\beta = 3/4$) is established for densities larger than $\sim 10^{19}$ cm^{-3} for temperatures of 5×10^7 K. The corresponding densities for sulfur, argon and calcium are at least 4×10^{18} cm^{-3} at temperatures for which the Be-like stage attains its maximum abundance. It is concluded, then, that appreciable Fe XXIV and Fe XXV Kα emission does not occur during solar x-ray flares. Nevertheless, Fe XXIV $1s^2 2p - 1s^2 2s$ and Fe XXV $1s2p - 1s^2$ transitions have been observed in flare spectra (Neupert and Swartz 1970; Doschek et al. 1971, Vasil'yev et al. 1972). However, K-shell ionization processes are not involved in either case. The upper level of the Fe XXV transition is populated by excitation from the ground state through electron collisions, while Gabriel and Jordan (1969) and Gabriel (1972) have shown that the $1s^2 2p$ levels of the Fe XXIV transitions are populated either by dielectronic recombination of Fe XXIII or inner-shell excitation in Fe XXIV.

Iron Kα emission during intense soft x-ray bursts has been reported by Neupert et al. (1967), Neupert (1971) and Doschek et al. (1971), forming either discrete line structures or a long wavelength 'tail' to the prominent Fe XXIV and Fe XXV lines seen between 1.85 and 1.87 Å (Neupert and Swartz 1970, Doschek et al. 1971, Vasil'yev et al. 1972). We have compared our calculations with the flux of Kα emission measured by Neupert (1971) during an intense flare on February 27, 1969. Neupert's spectrum shows a feature at $\lambda = 1.93$ Å which he identifies as Kα transitions in Fe XVII - XX ions. The flux of this line structure is estimated to be 2×10^4 photons cm^{-2} s^{-1} using a recent calibration for the instrument in question.

In our calculations, we use the temperatures and emission measures for this event deduced in a recent study by Saba (1972). He derives a two-temperature emission source with $n_e^2 V = 1 \times 10^{49}$ cm^{-3} at $T = 50 \times 10^6$ K and $n_e^2 V = 1 \times 10^{51}$ cm^{-3} at $T = 10 \times 10^6$ K. We find that the higher-temperature component would give rise to a flux of <0.1 photons cm^{-2} s^{-1} from all of the Fe XVII - XX ions according to Figure 5. The lower-temperature component would account for 3500 photons cm^{-2} s^{-1}. The calculated flux is thus only 20% of the observed value.

The line emission seen at 1.93 Å in this event could conceivably be due to secondary photospheric effects such as fluorescence (Neupert et al. 1967, Doschek et al. 1971) or Compton back-scattering (Tomblin 1972). Doschek et al. (1971) have observed line emission at the position of the Fe II Kα transition during flares on the solar disk. Since the feature is apparently absent in limb flares, they consider this to be evidence for fluorescence from photospheric layers. The nearness of the Fe II Kα line to Fe XVII Kα - House (1969) calculates a separation of only 0.009 Å - could imply that fluorescence accounts for some of the structure Neupert observed. However, the February 27, 1969, flare occurred about 65^o away from the solar center and the fluorescence contribution should thus be small. Similarly Compton back-scattering from photospheric layers is likely to be weak for this case on the basis of calculations by Tomblin (1972).

It is possible that a detailed consideration of the flare temperature distribution must be made, perhaps in the manner used by Batstone et al. (1970) for their study of active regions. Batstone et al. examine soft x-ray line fluxes to deduce emission measures in temperature increments of 2×10^6 K between 2.5×10^6 and 8.5×10^6 K, and find that smaller emission measures are associated with higher temperatures. A multi-temperature model or one having a continuous distribution of the temperature derivative of emission measure such as that recently proposed by Chambe (1972) could be found to be applicable for the February 27, 1969 event. It may then be found that the discrepancy between the calculated and observed iron Kα emission can be removed.

5. Conclusions

We have calculated the expected flux of Kα line emission from sulfur, argon, calcium and iron during both thermal and non-thermal solar x-ray events. Such emission is shown to be weak during the course of most of the non-thermal hard x-ray bursts that Kane and

Anderson (1970) have observed. If Compton back-scattering is significant at high energies, the flux is reduced still further for disk flares, but we note that the strong, near-limb burst of June 26, 1968 would have produced ~100 photons cm^{-2} s^{-1} of sulfur and iron Kα emission. The impulsive hard x-ray bursts may in general be too short-lived for much Kα emission, though a greater chance of detecting weak fluxes is offered by the extended non-thermal burst observed by Frost and Dennis (1971). Meanwhile, it may be noted that sulfur Kα emission in particular depends sensitively on the lower energy limit of the non-thermal electron spectrum, assuming such a sharply defined boundary exists. This may be a means of determining the lower-energy limit.

During soft x-ray bursts, when temperatures of a few 10^7 K are attained, Kα emission from certain iron ions - specifically Fe XVIII - XXIII - may be important. Kα emission from Fe XXIV and XXV will not occur in any appreciable amounts because the K-shell ionization of Fe XXIII and XXIV in excited configurations is required, whereas nearly all such ions will in fact be in ground state configurations. The Fe XXIV and XXV lines that do occur at the same wavelengths as these Kα transitions arise from dielectronic recombination and inner-shell excitation (for Fe XXIV) and excitation by electron impacts (for Fe XXV).

The amount of thermal iron Kα emission during an event observed by Neupert (1971) is much larger than that calculated here on the assumption of a two-temperature emission source for the flare. The reason seems to be that a more detailed temperature structure for the flare must be considered. It may be that an analysis of the flare x-ray spectrum along the lines of Batstone et al.'s (1970) for an active region may be required.

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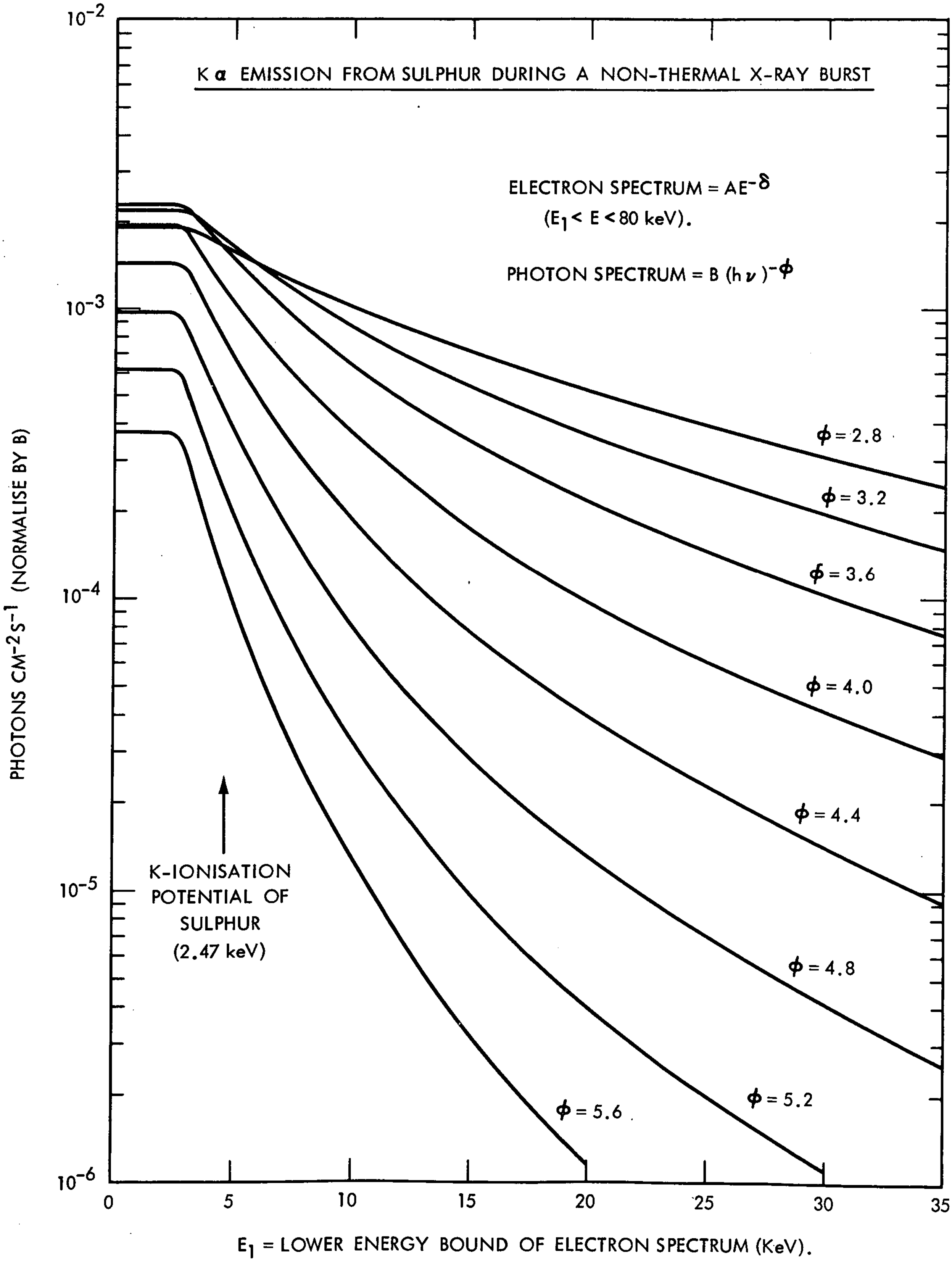
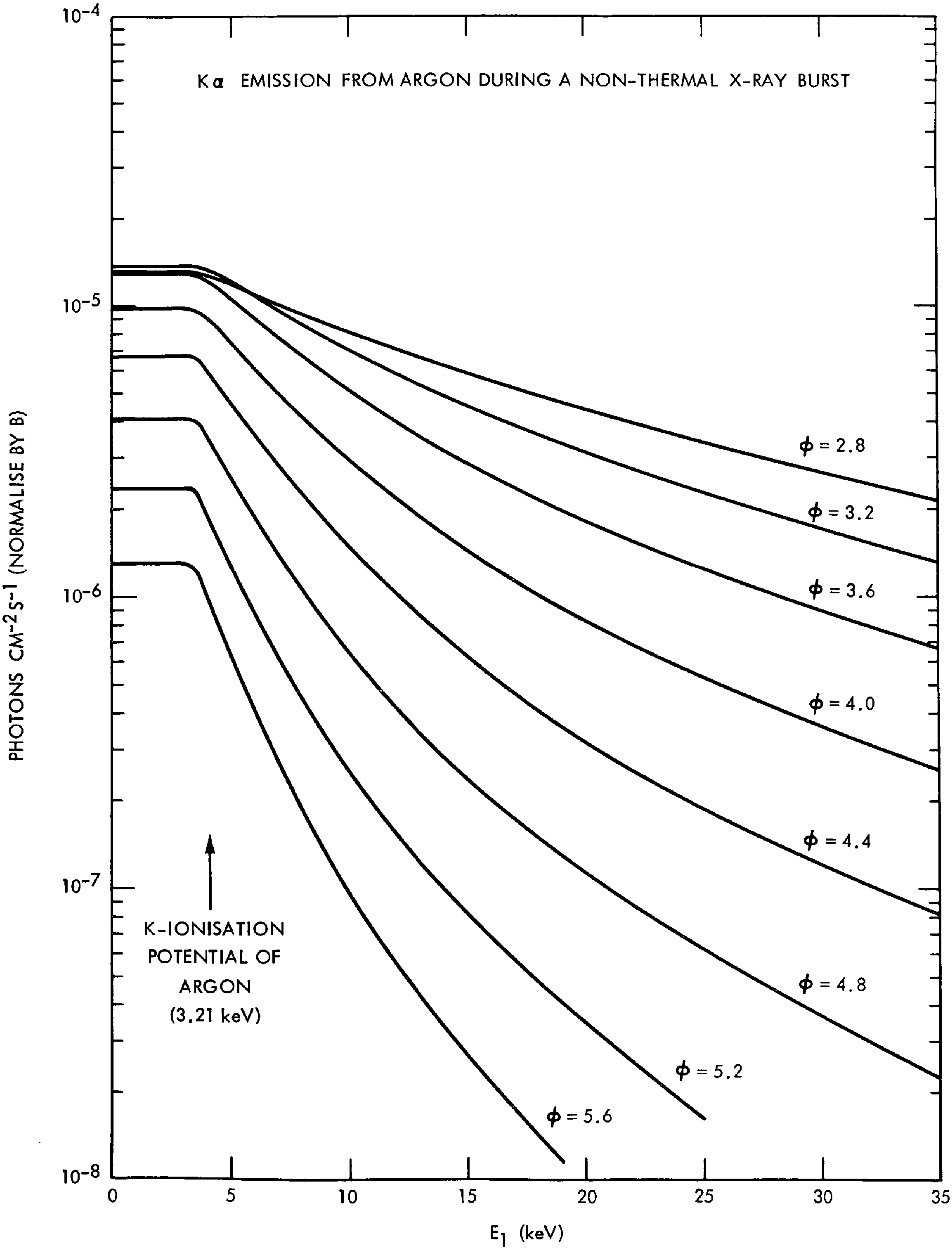
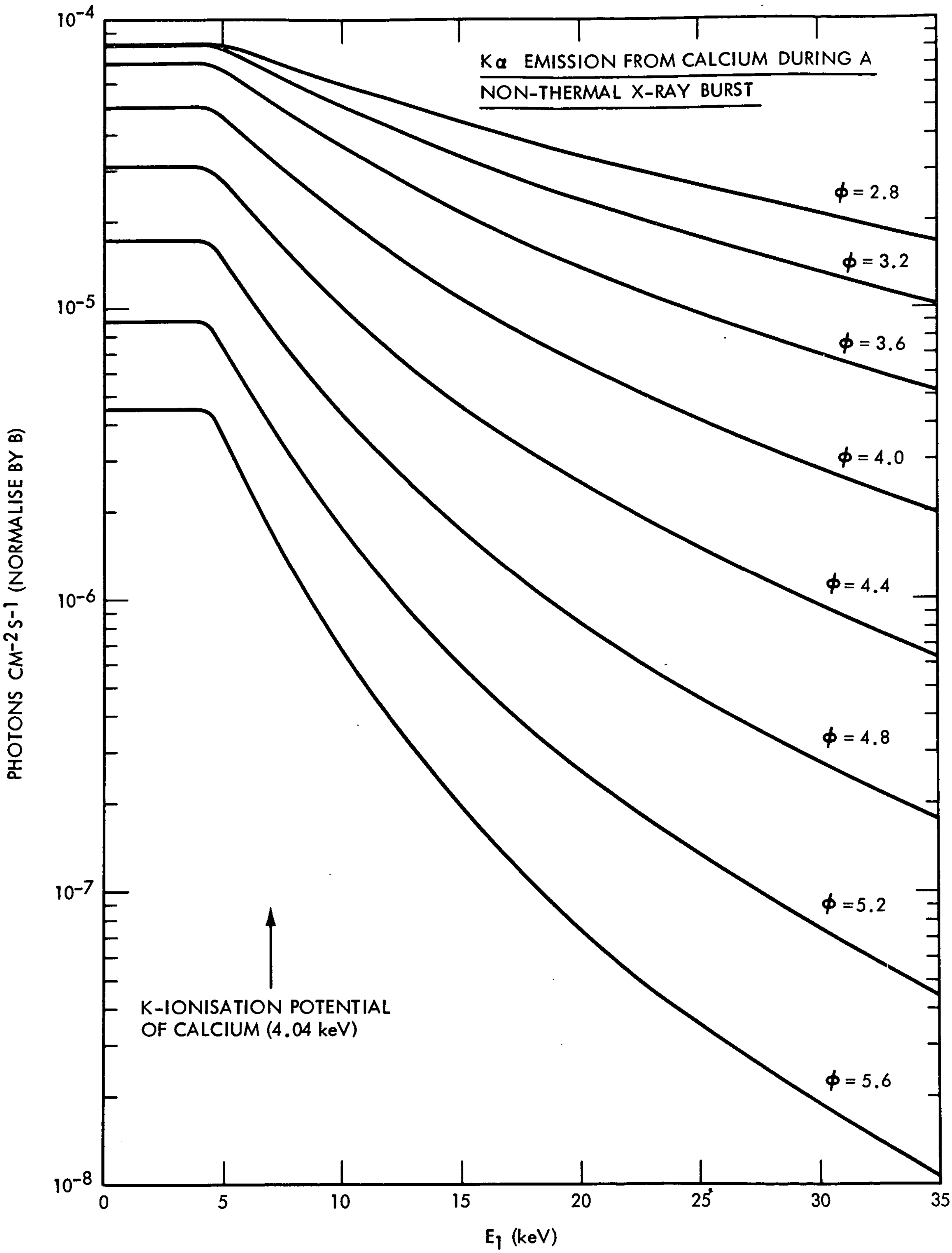


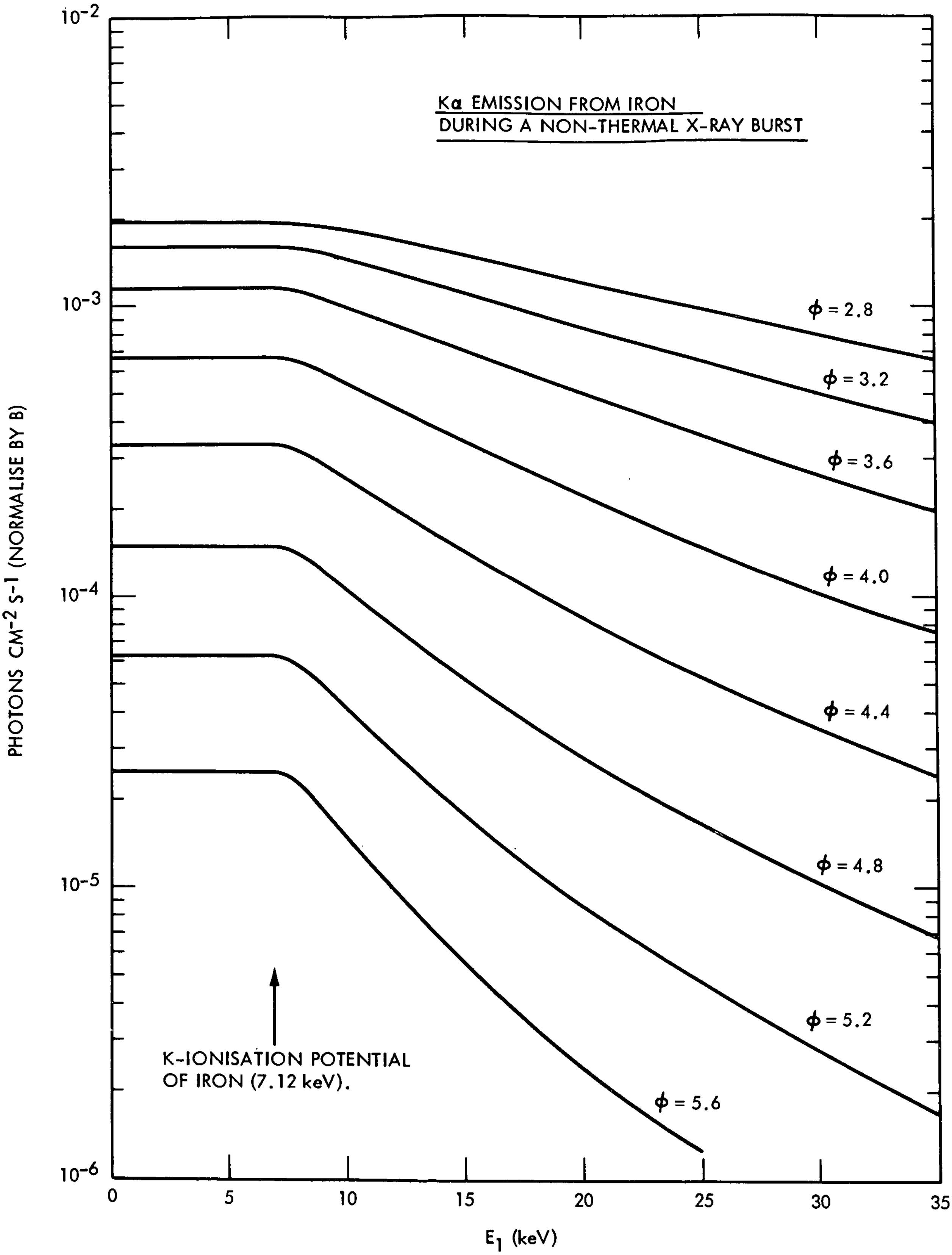
K α EMISSION FROM SULPHUR DURING A NON-THERMAL X-RAY BURST
ELECTRON SPECTRUM = $AE^{-\delta}$
($E_1 < E < 80$ keV).
PHOTON SPECTRUM = $B (h\nu)^{-\phi}$
$\phi = 2.8$
$\phi = 3.2$
$\phi = 3.6$
$\phi = 4.0$
$\phi = 4.4$
$\phi = 4.8$
$\phi = 5.2$
$\phi = 5.6$
K-IONISATION
POTENTIAL OF
SULPHUR
(2.47 keV)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0
5
10
15
20
25
30
35
PHOTONS $CM^{-2}S^{-1}$ (NORMALISE BY B)
E_1 = LOWER ENERGY BOUND OF ELECTRON SPECTRUM (KeV).

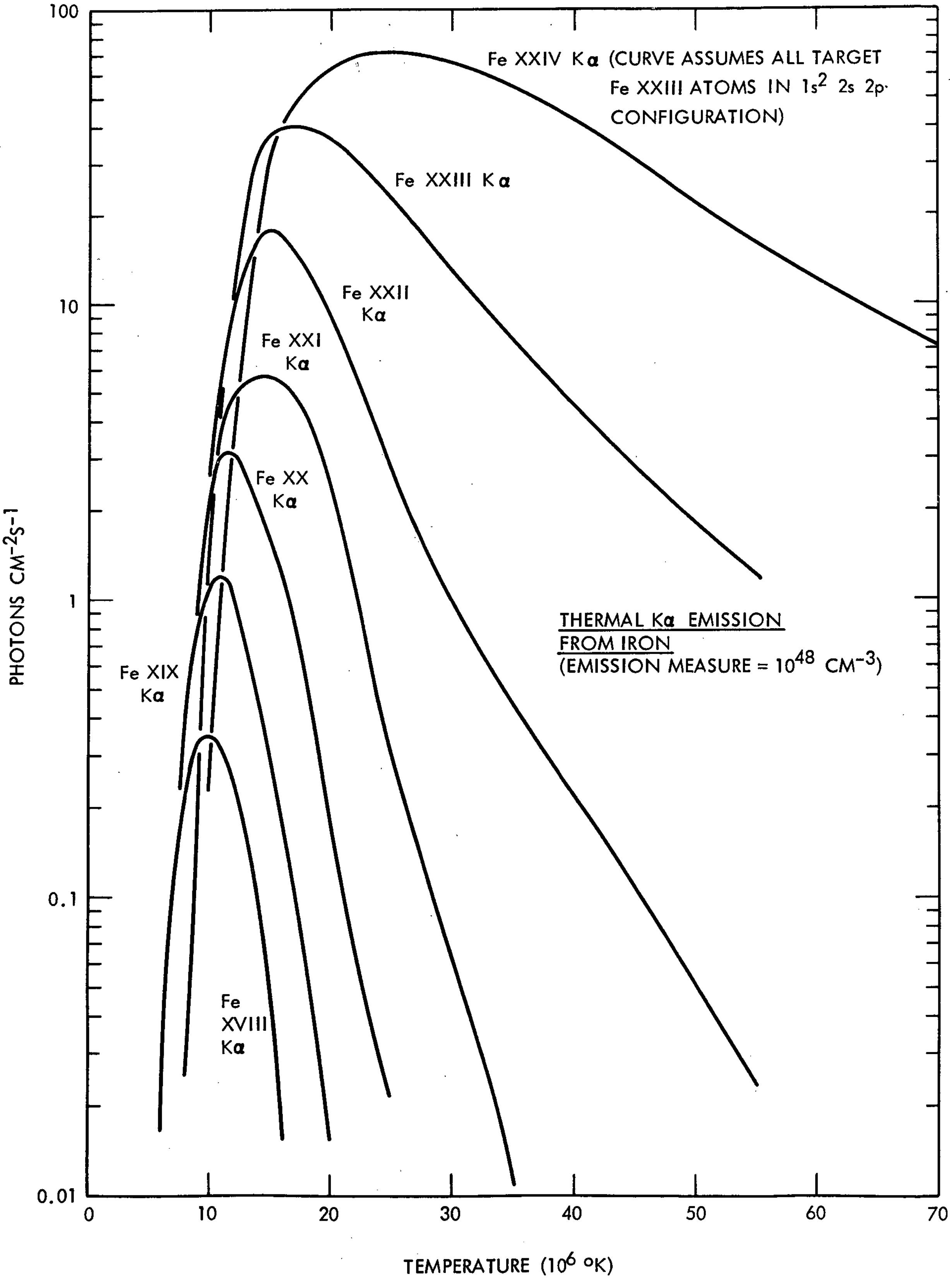

Kα EMISSION FROM ARGON DURING A NON-THERMAL X-RAY BURST
PHOTONS CM-2 S-1 (NORMALISE BY B)
10-4
10-5
10-6
10-7
10-8
0
5
10
15
20
25
30
35
E1 (keV)
K-IONISATION POTENTIAL OF ARGON (3.21 keV)
φ = 2.8
φ = 3.2
φ = 3.6
φ = 4.0
φ = 4.4
φ = 4.8
φ = 5.2
φ = 5.6



Kα EMISSION FROM CALCIUM DURING A NON-THERMAL X-RAY BURST
PHOTONS CM-2 S-1 (NORMALISE BY B)
10-4
10-5
10-6
10-7
10-8
φ = 2.8
φ = 3.2
φ = 3.6
φ = 4.0
φ = 4.4
φ = 4.8
φ = 5.2
φ = 5.6
K-IONISATION POTENTIAL OF CALCIUM (4.04 keV)
0
5
10
15
20
25
30
35
E1 (keV)

25


Kα EMISSION FROM IRON
DURING A NON-THERMAL X-RAY BURST
ϕ = 2.8
ϕ = 3.2
ϕ = 3.6
ϕ = 4.0
ϕ = 4.4
ϕ = 4.8
ϕ = 5.2
ϕ = 5.6
K-IONISATION POTENTIAL
OF IRON (7.12 keV).
PHOTONS CM^{-2} S^{-1} (NORMALISE BY B)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0
5
10
15
20
25
30
35
E_1 (keV)


100
10
1
0.1
0.01
PHOTONS $CM^{-2}S^{-1}$
0
10
20
30
40
50
60
70
TEMPERATURE (10^6 °K)
Fe XXIV Kα (CURVE ASSUMES ALL TARGET
Fe XXIII ATOMS IN $1s^2$ 2s 2p
CONFIGURATION)
Fe XXIII Kα
Fe XXII Kα
Fe XXI Kα
Fe XX Kα
Fe XIX Kα
Fe XVIII Kα
THERMAL Kα EMISSION FROM IRON
(EMISSION MEASURE = 10^{48} CM^{-3})

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